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PROCESSING PROCEDURES FOR THE VALIDATION OF A COMPUTER-AIDED DE--ETC(U)

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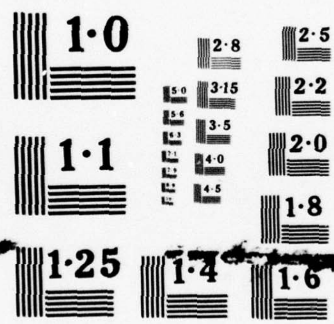
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(6) PROCESSING PROCEDURES FOR THE VALIDATION OF A COMPUTER-AIDED DETECTION MODEL. [redacted]

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1. INTRODUCTION

(U) The classical approach to sonar target detection has been to provide a sonar operator with visual displays of the information received by the sonar system. This approach is known to have the following deficiencies:

(a) The data rates associated with a modern sonar system often exceed the capacity provided by state-of-the-art display technology and/or the capacity of the operator to process the information displayed.

(b) Sonar operators do not perform in an optimal way when faced with a rare event situation.

(c) It is very difficult to obtain consistent application of the same detection criteria when several sonar operators are used.

(U) The deficiencies listed above have motivated the investigation of the use of a computer to aid in the detection process. Preliminary investigation of a computer-aided detection model developed under contract NObsr-93352 indicates that a CAD model will yield unalerted detection performance approximately equal to that of an alerted operator. Furthermore, the performance of the CAD model is not degraded by rare event situations. The investigations carried out to date are based largely on computer generated data.

(U) The aim of the work discussed in this report is to achieve the next logical step, that of validating the CAD model performance by the application of the model to a large volume of recorded sea test data. The purpose of this report is to describe in detail the processing that is being done to accomplish this work. Included in this report is a detailed description of the data base to be used and the data reduction to be performed. The examples provided in this report were

produced by processing digital computer generated data and do not represent any sea data processing. For this reason, they should be considered only as representatives of the type of results which will be produced when actual sea data is processed.

(U) To accomplish this validation study, the CAD model is being applied directly to the data obtained during the technical evaluation of the AN/SQS-26. From this application, modified ROC curves are obtained for the CAD model. These curves provide a measure of the absolute performance of the model, permitting an assessment of its validity. Simultaneously, using the recorded operator responses, similar measures of operator performance are determined in order that comparison of operator and CAD model performance may be obtained.

(U) Using the information concerning the relative performance of the model gained from this comparison and the absolute performance of the model gained from the modified ROC curves, an overall evaluation of the computer-aided detection model is made.

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2. DETAILED DESCRIPTION OF DATA PROCESSING PROCEDURES WITH EXAMPLE OUTPUTS

(U) Detailed descriptions of the data processing procedures implemented to accomplish the validation of the CAD model are provided in the following sections. Primary emphasis is placed on the data processing procedures applied external to the basic CAD model. A detailed description of the internal data processing procedures of the CAD model is provided in Appendix A.

(U) To provide a start point for the description of the data processing procedures a description of the sea test data base to be used is provided in section 2.1. The description of the functional data flow within the processing procedures is provided in section 2.2. The organization of subsections within section 2.2 parallels the order in which basic computer runs are executed to accomplish the processing procedures. Where applicable examples of output data are provided.

2.1 DATA BASE DESCRIPTION

(U) The data gathered during the technical evaluation of the AN/SQS-26 sonar is being used as the data base for the validation of the CAD model. The TECHEVAL data includes about 4,000 ping cycles divided into about 200 runs of 20 ping cycles per run. The output of the shipboard signal processing unit (and other information) is recorded on 1 inch 14 channel instrumentation tape by an analog data acquisition system (ADAS). The recorded analog information is converted to digital format as part of the data processing being accomplished in support of TECHEVAL. The digitized data is formatted to have one digital file for each ping cycle. The data within each digital file consists of samples taken during two time gates. The first time gate occurs during transmit and is approximately ½ second long. The second time gate occurs during receive and

is approximately 12 seconds long. During each time gate data is sampled at a 1 KC rate from nine analog channels. Also a time code channel, recorded on the analog tape, is decoded and stored in the digital file at a 1 KC rate. The nine analog channels which are sampled are:

(1) SSI

(2) CW AGC IN

(3) CW IN

(4) CW OUT

(5) CP AGC IN

(6) CP IN

(7) CP OUT

(8) 3-BIT CP OUT

(9) DELTIC REF.

(U) The position of the second time gate, mentioned above, is controlled by the sonar operator's cursor. In this way the 12 second interval always overlaps the target signal and the transponder signal.

(U) All of the information contained in the digital files is not needed for the current program to validate the CAD model. The information which will be used is:

(1) Time Codes. By comparing the time codes in the first time gate with those in the second time gate the time of signal arrival relative to the time of transmit is determined.

(2) CP OUT. The output of the CODED PULSE processor is being used as the basic input to the CAD model.

(U) At the beginning of each run approximately 11 to 12 seconds of calibration data is sampled in the same format as the ping cycle data. The use of the calibration data will be described in more detail in section 2.2.1.

(U) In addition to the sonar data discussed above, the sonar operator logs a response to the signal received on each ping. The responses are: NO SIGNAL, QUESTIONABLE, WEAK, MEDIUM, and STRONG. These operator responses are punched on cards for use in the single ping comparison of CAD performance with operator responses.

2.2 FUNCTIONAL DATA FLOW

(U) The discussion of the functional data flow is best done by dividing this section into four smaller subsections. Section 2.2.1 and section 2.2.2 will be concerned with the data reduction necessary to produce the modified receiver operating characteristic curves described in section 2.2.3. Comparison of the CAD model performance with operator performance will be discussed in section 2.2.4.

2.2.1 Phase I Data Reduction

(U) Before the TECHEVAL data described in section 2.1 can be used in the CAD validation process some preliminary data reduction is necessary. Figure 1 is a diagram giving a condensed description of the data reduction process. A more detailed discussion will follow.

(U) At the beginning of each run approximately 11 to 12 seconds of calibration data is being sampled in the same format as the ping cycle data. This calibration data contains signals which were injected by the sonar system test set. The signal-to-noise ratio of the injected signals is very large and for this reason the amplitude of the signal peaks at the output of the clipped coded pulse processor provides a calibration of the maximum obtainable output signal. The calibration data processing shown in Fig. 1 measures the amplitude of these output signal peaks and uses the resulting value to calculate the mean and standard deviation at the output

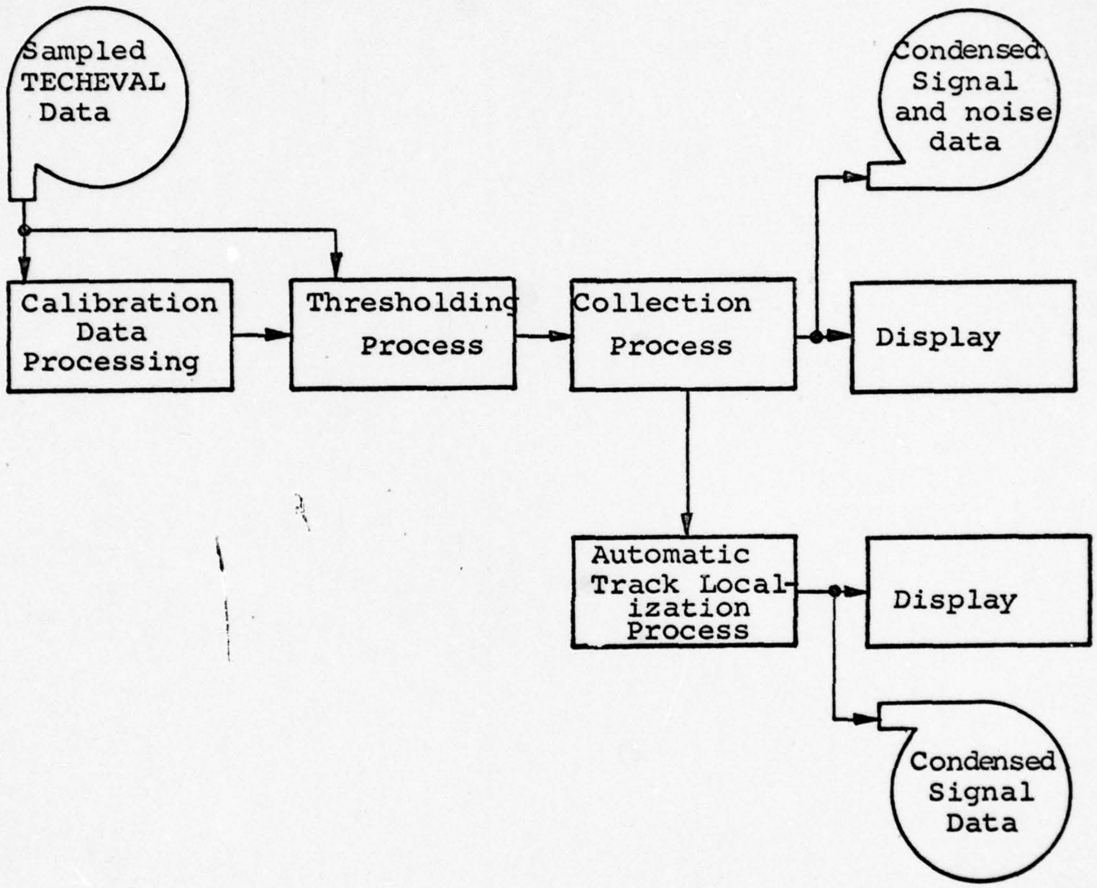

Fig. 1 Block Diagram of Phase I Data Reduction

of the coded pulse processor. The calculated values of mean and standard deviation are passed to the thresholding process.

(U) The thresholding process referred to in Fig. 1 uses a log likelihood ratio threshold to produce an array containing the value (in log likelihood ratio) and location of each peak that exceeds this threshold. The purpose of this processing is to condense the large volume of uniform time function samples to peak sample events and to use the mean and standard deviation obtained from the calibration data to transform these peak amplitudes to a normalized quantity, in this case log likelihood ratio.

(U) It is evident that this thresholding process is more involved than the normal thresholding process. The data is first scanned to select the local peaks. (A sample x_i is a local peak if and only if $x_i > x_{i-1}$ and $x_i > x_{i+1}$). Further processing is done to resolve the ambiguity of two local peaks occurring closer than the resolution of the sonar. Each local peak is then converted to a log likelihood y_i through the relation

$$y_i = A\left(\frac{x_i - \mu}{\sigma}\right) + B$$

where

μ = the mean value of the data calculated from the calibration data

σ = the sigma of the data calculated from the calibration data

A and B = the conversion constants for the log likelihood ratio L, L = Ax + B.

(U) After conversion to log likelihood ratio is accomplished, the thresholding process makes use of the time code data to express

the position of each local peak as an arrival time relative to the transmit time of the signal. Thus the entries in the array produced by this process consist of normalized peak amplitudes expressed in units of log likelihood ratios and corresponding peak positions expressed in units of milliseconds relative to the transmit time.

(U) The array resulting from the thresholding process is generated on a ping by ping basis. Therefore in order to obtain information about the entire run the collection process is needed. This collection process collects the peak amplitudes and positions from each ping into one large array which is stored onto magnetic tape for later processing. The new array is also processed to obtain a computer generated display. Figure 2 is an example of this type of display. The numbers down the left side of the display identify the ping cycles. The horizontal displacement represents time of arrival or range. The digits within the display are dB in excess of some given dB value. The purpose of this display is to verify visually the track chosen by the automatic track localization process described below.

(U) To this point the information stored in the array produced by the collection process includes both signal peaks and noise peaks. However, in order to produce the desired modified ROC curves it is necessary to separate the signal information from the noise information. To obtain this separation the automatic track localization process is implemented.

(U) In the automatic track localization process, signal peaks belonging to a single track are extracted from the input array which is provided by the collection process. Since the noise and signal peaks input to the process were obtained from

Fig. 2 Display of Condensed Signal and Noise Data

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28                                                  3       0                                    2
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30                1                    1              2
31
32                   1                                1
33                                      0             2
34                                                  2                        0             0
35                                     1                                    20               1
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37                                                         1                   3
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N consecutive pings, a maximum of N signal peaks and positions may define a single track. (Less than N may be obtained in those cases where the track does not contain a signal peak on some ping.)

(U) To locate the signal peak, the automatic track localization process first determines the largest peak in the entire input array. An initial assumption is made that this largest peak (called the "pivot" peak) belongs to the track. Peak positions and amplitudes on each ping (excluding the ping containing the pivot peak) are then examined and a amplitude-weighted slope density function is calculated. The slope of a given peak position to the pivot peak position contributes to the density function by an amount related to its amplitude. After all peaks have been examined, the slope corresponding to the maximum of the density function is selected and is used to define a straight line through the pivot peak. This straight line is the first approximation to the track.

(U) The straight line track approximation is used to obtain an initial set of signal peaks. A signal peak on a given ping is a candidate for inclusion in the track if its amplitude, degraded by the deviation of its position from the straight line approximation exceeds a set threshold. The largest such peak on each ping is selected to form the initial set of signal peaks.

(U) The remainder of the automatic track localization process consists of an iterative procedure in which successive least-squares quadratic fits are made to signal peak positions beginning with the initial set of signal peaks described above. After each quadratic fit has been determined, the input array of peaks is examined to see which peaks belong to the track defined by the quadratic curve. The peaks selected then become

the basis for the next curve-fitting step. The process terminates when two successive quadratic fits define tracks containing the same set of signal peaks.

(U) At the termination of the automatic track localization process, the signal peak amplitudes and positions defining the track are produced in an output array. The data is stored onto a magnetic tape to be processed later and is processed to obtain a computer generated display to illustrate the selected track. From Fig. 3 it is seen that the format of this display is exactly the same as the previously described display. Therefore comparison of the two displays to verify the results of the automatic track localization process is possible.

2.2.2 Phase II Data Reduction

(U) The next step in the validation process is to put the data into a form such that modified ROC curves with signal-to-noise ratio and number of pings of integration as parameters may be generated.

(U) To produce the modified ROC curves two types of curves are needed:

(1) False alarm rate curves as a function of the likelihood ratio threshold, and

(2) Probability of detection curves as a function of the likelihood ratio threshold.

The false alarm rate curves can be generated by processing a large volume of noise through the CAD model. Probability of detection curves are generated from the signal data that has been processed by the CAD model. Details of how these curves are generated and how they are used to produce the modified ROC curves are given in section 2.2.3. However, from the above brief discussion of these two types of curves it is evident that

Fig. 3 Display of Condensed Signal Data

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it will be necessary to remove the signal from the signal plus noise data before any further processing can be accomplished.

(U) To aid in the discussion of the Phase II data reduction a block diagram is provided in Fig. 4.

(U) The condensed signal and noise data referred to in Fig. 4 consists of the amplitudes and location values produced by the collection process discussed earlier. From the automatic track localization process, also described in the previous section, the amplitudes and locations of the samples contributing to a track are known. The track deletion process uses this information to remove the signal track from the signal plus noise array.

(U) The resulting noise only data is cataloged by the sorting process to obtain a tabular representation of the noise probability density function. This table is output to magnetic tape for later processing. The noise only data is also processed through the CAD model and into the sorting process to obtain the noise probability density function applicable to the output of the CAD model. Likewise, this table is output to magnetic tape for later processing.

(U) As explained above the probability of detection curves are produced from the results obtained by processing signals through the CAD model. Details concerning the CAD model may be found in Appendix A. For discussion here, it is sufficient to state that the CAD model implements ping to ping integration of the logarithm of the likelihood ratio along consistent target tracks. The expected track strength (or track likelihood ratio) increases as the number of pings increases. This result is consistent with results obtained with optical ping to ping integration.

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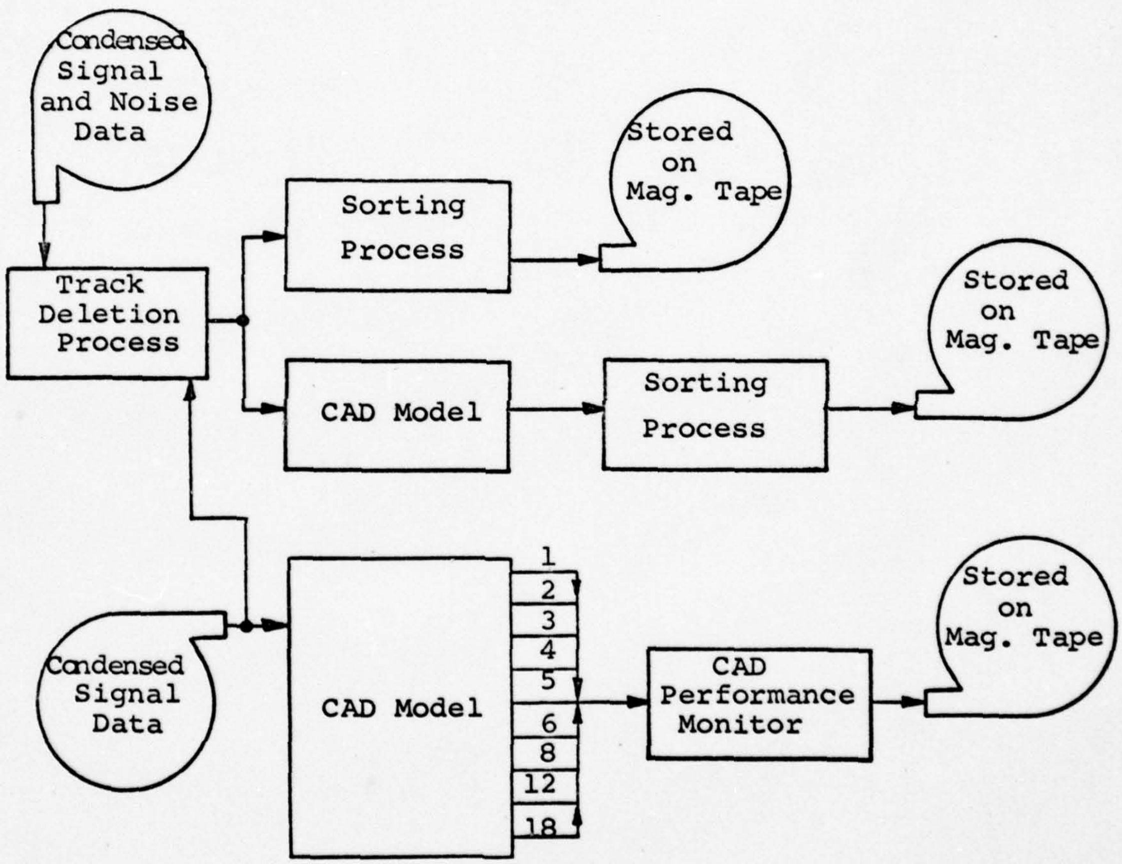

Fig. 4 Block Diagram of Phase II Data Reducation

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(U) From the discussion above it is apparent that the probability of detection associated with a ping to ping integrating system depends on the number of pings for which integration is accomplished as well as the average signal-to-noise ratio. It is also evident that the performance of the CAD model varies with respect to the number of pings the model is allowed to access. For this reason, to adequately evaluate the CAD model it will be necessary to vary the number of pings to be integrated, and thus determine the model's performance when allowed to access 3 pings, 4 pings, and so forth.

(U) As mentioned earlier, the TECHEVAL data consists of 200 runs of approximately 20 pings per run. It is possible to regroup the data in each of the ways indicated in Table I. Such variations in the number of pings per sequence will provide the desired parameterization of the number of pings for which integration will be carried out.

TABLE I Ping Sequences Available from TECHEVAL Data

Number of Pings Per Sequence, N	Number of Ping Sequences Available
1	4000
2	2000
3	1200
4	1000
5	800
6	600
8	400
12,18	200

(U) The CAD model has been modified to enable it to clear its memory after each sequence of pings has been processed in order to simulate having access to only those N pings.

(U) One way to process these sequences would be to take one value of N and determine the CAD performance for this particular N, then process another sequence, and so forth. However, in the interest of efficiency, all the sequences are processed through the CAD model each time a run is processed. Each of the nine channels shown in Fig. 4 that is produced by the CAD model refers to the information obtained by allowing the CAD model to have access to a different number of pings, namely 1,2,3,4,5,6,8,12, and 18.

(U) The CAD performance monitor uses information going into the CAD model as well as the data produced by the CAD model to obtain information packages consisting of three entries.

(1) N, the number of pings for which integration was performed.

(2) LLR, the maximum track log likelihood ratio obtained by the CAD model during the N pings processed.

(3) S/N, the estimated value of signal-to-noise ratio for the N ping sequence going into the CAD model.

(U) The estimated signal-to-noise ratio refers to a signal-to-noise ratio of the form

$$\frac{P-\bar{x}}{\sigma}$$

where

P is the signal peak

$\bar{x}$ is the noise mean

σ is the standard deviation of the noise

If the signal was detected on all N pings (i.e. no missed pings)

then the estimated signal-to-noise ratio will be a straightforward average. If some pings occur which do not contain signals the average signal-to-noise ratio is calculated as,

$$\overline{\frac{S}{N}} = \frac{1}{N} \left[\sum_{i=1}^{K} \left(\frac{S}{N}\right)_i + (N-K)\left(\frac{S}{N}\right)_{est} \right]$$

where

K = the number of pings which contained a detected signal.

$\left(\frac{S}{N}\right)_i$ = the signal-to-noise ratio for the pings which contain a detected signal.

$\left(\frac{S}{N}\right)_{est}$ = an estimate of the signal-to-noise ratio for the missed pings. The value of $\left(\frac{S}{N}\right)_{est}$ is calculated by a table lookup using $\frac{N-K}{N}$.

The values of $\frac{S}{N}$ and LLR described above are required to generate the probability of detection curves.

2.2.3 Statistical Data Retrieval and Summary Processing

(U) Unlike Phase I and Phase II data reduction the statistical data retrieval and summary processing is not run oriented, but rather makes use of information from all the runs accumulated in the Phase II data reduction processing. At this point in the validation study the data has been reduced to a form which can now be used to generate probability of detection curves and false alarm rate curves. These curves in turn will be used to produce the desired modified receiver operating characteristic curves.

(U) As described earlier the signal data has now been condensed to a set of triplets. These triplets contain information about the number of pings to which the CAD model had

access, the estimated signal-to-noise ratio of these pings, and the maximum track log likelihood ratio which is a measure of the CAD model's performance when integrating over these N pings. It is desired to evaluate the CAD model for each value of N processed. Therefore, this set of triplets must first be divided into groups, each group containing triplets concerned with a particular value of N. This grouping thus produces one of the parameters necessary for the modified ROC curves, namely the number of pings for which integration was performed. From this point on each group will be processed in the same manner, but separately.

(U) The other parameter required to produce the modified ROC curves is signal-to-noise ratio. To obtain this parameter each group of triplets is first sorted according to the estimated signal-to-noise ratio provided by each triplet. This sorting rank orders the triplets with respect to the signal-to-noise ratio.

(U) The next step is to divide each group into categories based on the value of the measured signal-to-noise ratio. Within each new subgroup, or category, an average estimated signal-to-noise ratio which will be associated with the curve produced by this category is calculated. The data within each category is now placed in a likelihood ratio histogram from which the probability of detection as a function of likelihood ratio threshold is obtained. The probability of detection curve tells how the model performed for a particular N and a particular signal-to-noise ratio. A set of probability of detection curves with signal-to-noise ratio parameterized is obtained for each of the nine different values of N. Examples of the curves which are generated are given in Figs. 5, 6, 7, 8, 9, 10, and 11. From these examples it can be seen that a least squares fit of a straight line is applied to each curve before any plotting is done.

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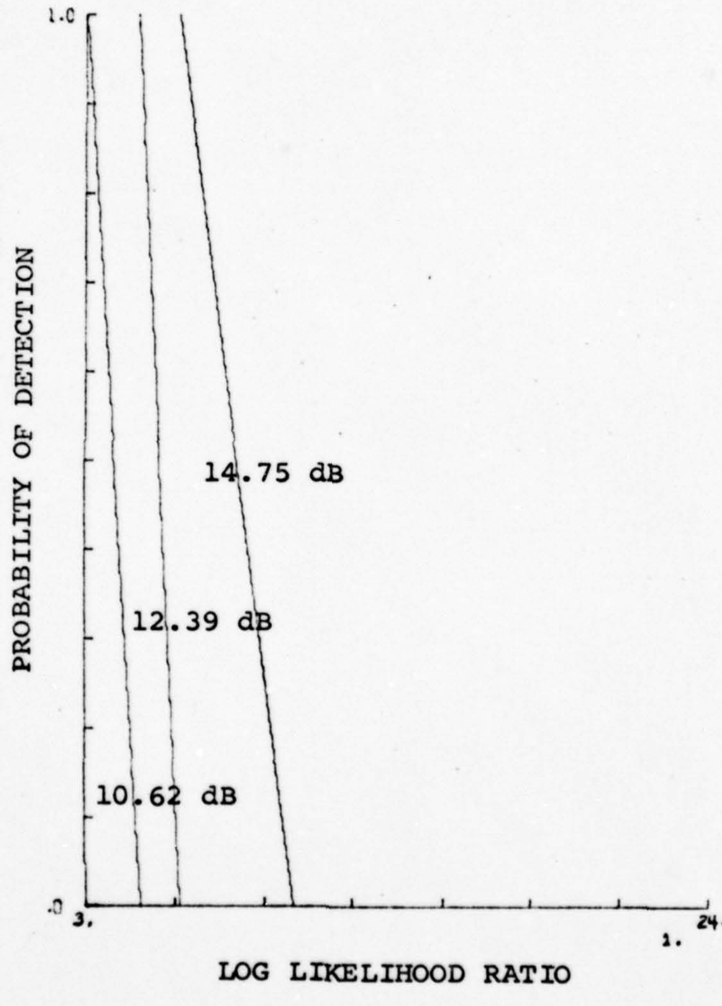

Fig. 5 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Processing Single Ping Events

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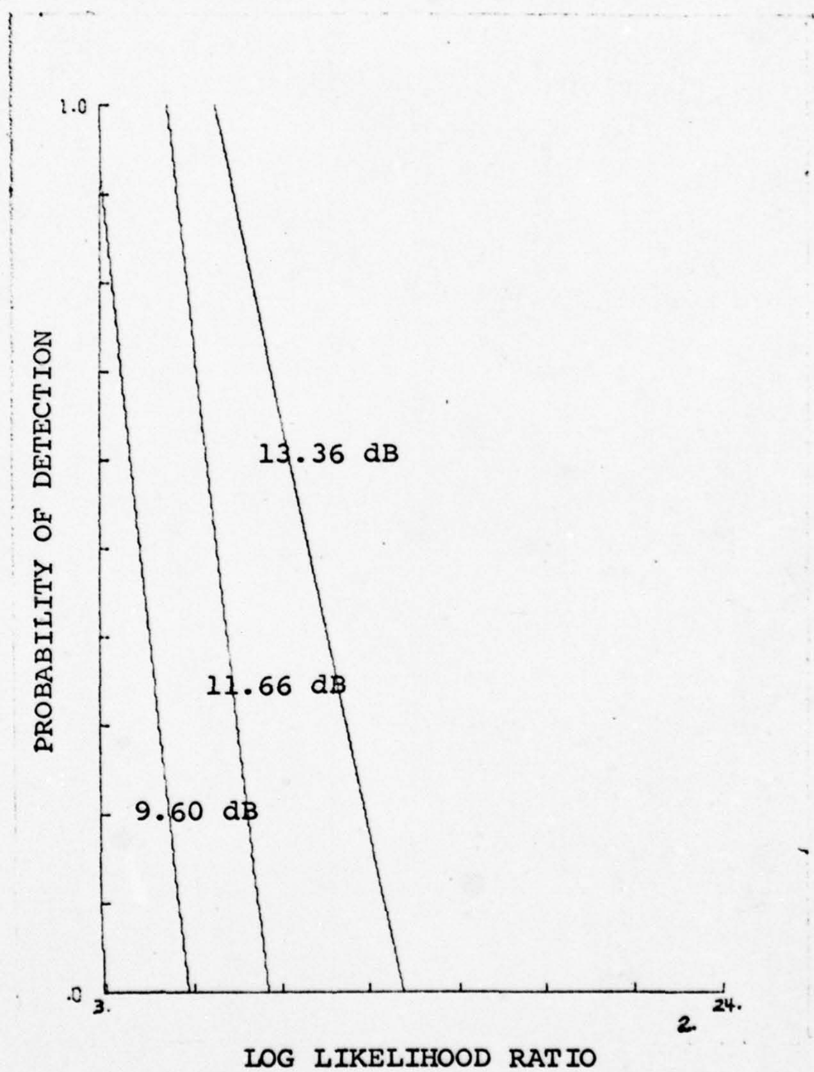

Fig. 6 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Sequence of 2 Pings

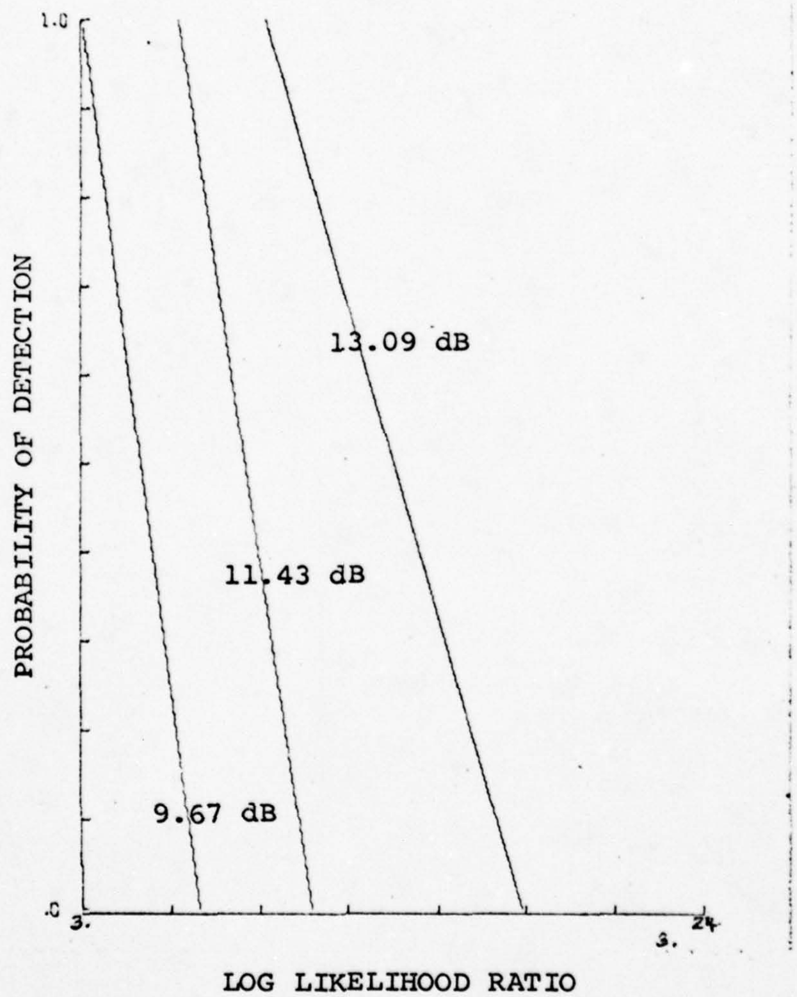

Fig. 7 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Seqeuence of 3 Pings

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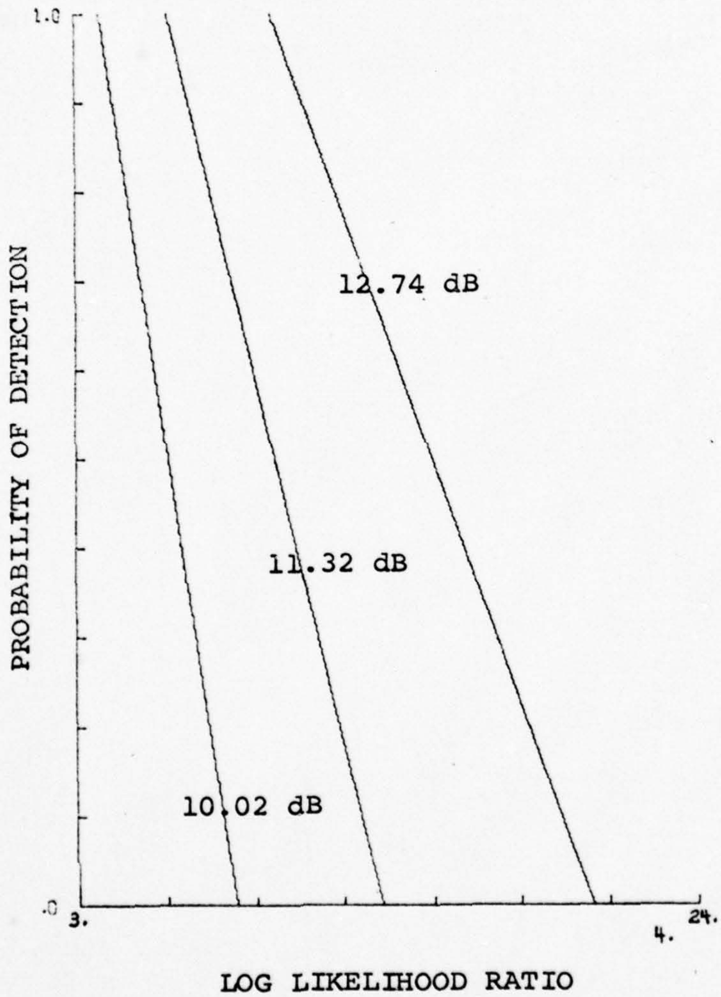

Fig. 8 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Sequence of 4 Pings

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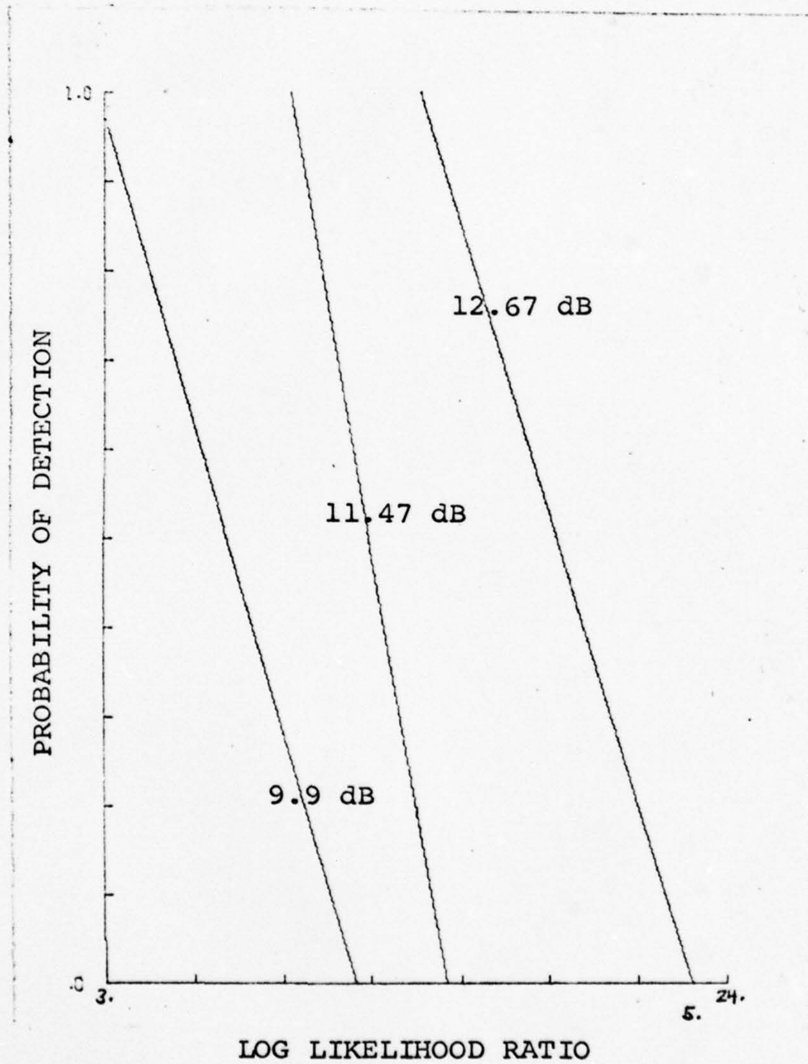

Fig. 9 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Sequence of 5 Pings

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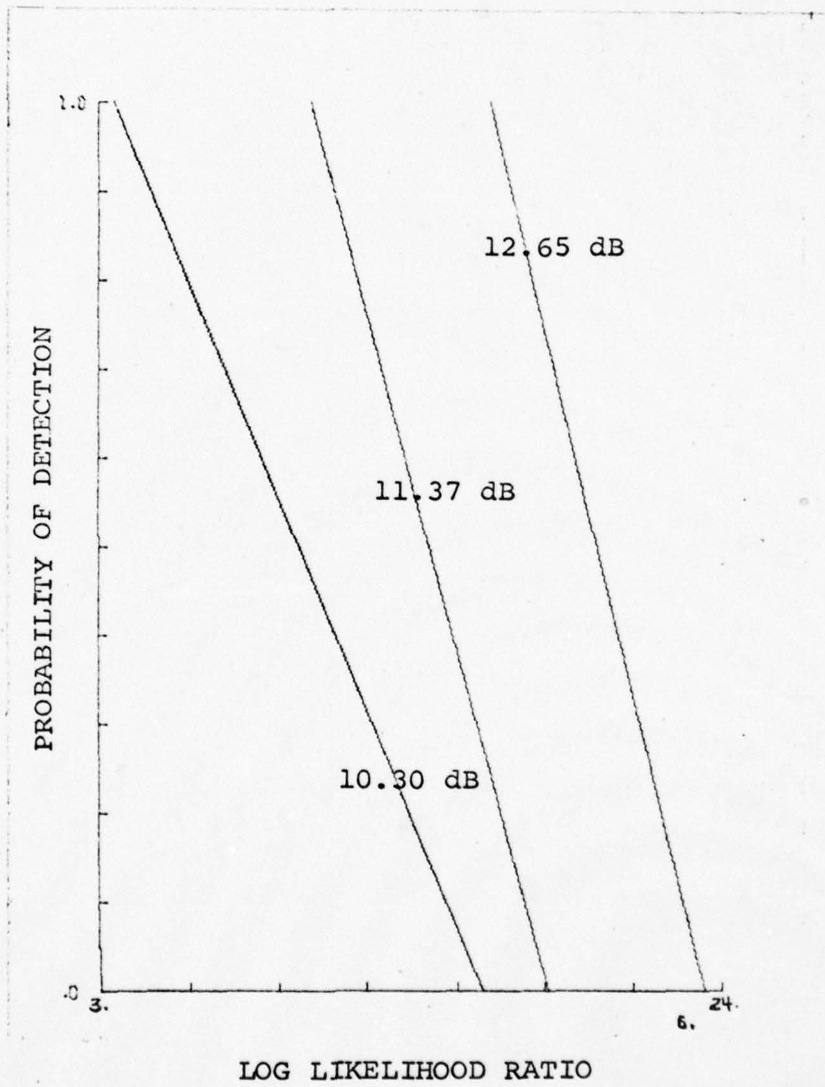

Fig. 10 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Sequence of 6 Pings

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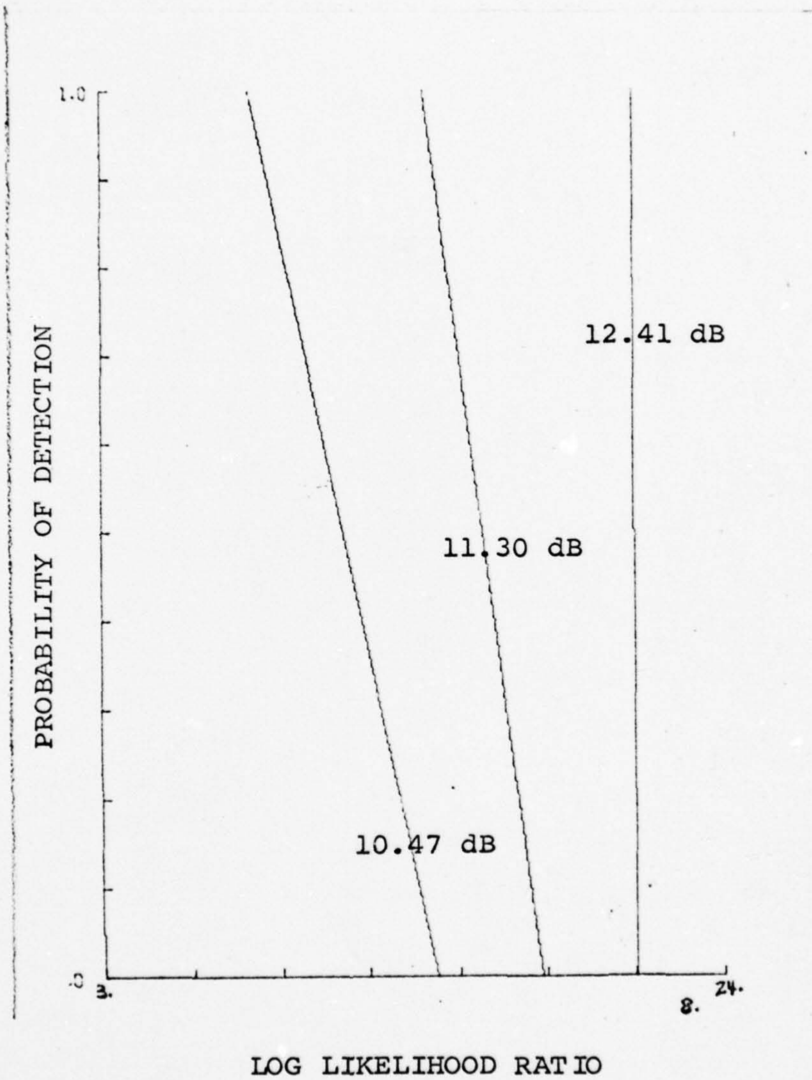

Fig. 11 Probability of Detection vs. Track Log Likelihood Ratio for the CAD Model Integrating Over a Sequence of 8 Pings

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(U) Two false alarm rate curves are now needed before the modified ROC curves can be generated. The first curve, which is used to generate the modified ROC curve for the CAD model processing on a single ping basis, is obtained by using the noise processed before the CAD model described in section 2.2.2. A false alarm rate curve is determined by using the noise samples which are still in the form of peak log likelihood ratios and a specified time interval over which the false alarms occurred. By processing a finite amount of data, as is being done here, one can never get false alarm rates of less than 1/T, where T is the time interval over which the false alarms occurred. However, the curve produced is not an adequate curve to completely evaluate the CAD model. This is due to the fact that for the CAD model evaluation false alarm rates in the order of one per day are desired. To directly produce such a curve would necessitate the processing of a prohibitive amount of data. For this reason it is desired to have an analytical expression of the curve produced from processing a finite amount of data that will be meaningful in the desired range.

(U) Since the output of the coded pulse processor is obtained by envelope detection of a zero mean Gaussian process one would expect the distribution of the noise peaks to be approximately Rayleigh. Therefore, the log of the false alarm rate can be written as a quadratic of the form $A + Bx + Cx^2$. The values of A, B, and C are obtained by applying the least mean square fit to the table of false alarm rate values calculated from the noise data. The curve produced by this quadractic expression thus produces the desired false alarm rate curve. The first curve of false alarm rate as a function of log likelihood ratio threshold can now be plotted. Both the original curve obtained from the processed noise data and the extrapolated curve are shown in Fig. 12.

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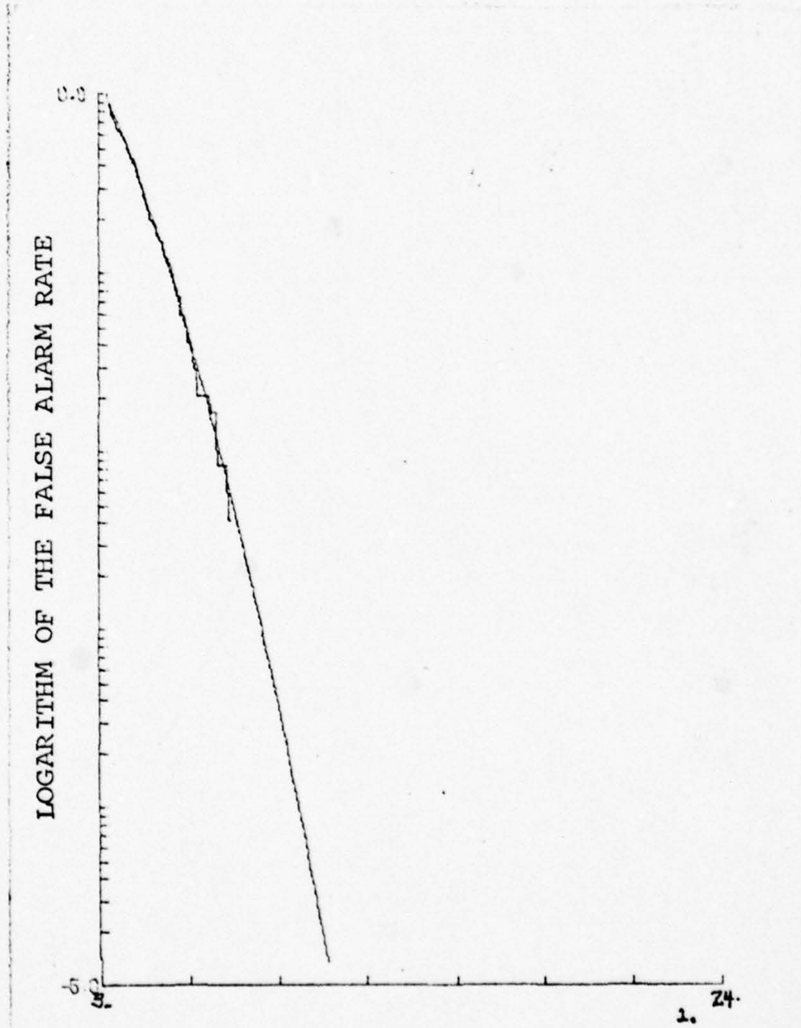

Fig. 12 False Alarm Rate Curve for Noise Data Without Processing by the CAD Model

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(U) The second curve, which is used to generate modified ROC curves for the CAD model processing on a multiple ping basis, is obtained in a similar manner as the curve described above. However, in this case, the noise data used is that obtained by processing the noise through the CAD model. Similarly, both the original curve and the extrapolated curve can be seen in Fig. 13.

(U) The probability of detection curves and the false alarm rate curves are both described as a function of log likelihood ratio threshold. Therefore using this common axis the false alarm rate curve for noise without CAD processing (Fig. 12) is mapped with the probability of detection curves for the sequence N=1 (Fig. 5) to obtain a set of curves of probability of detection vs. false alarm rate (Fig. 14), the desired modified ROC curve for the CAD model operating on a single ping event. Similarly, the false alarm rate curve for noise with CAD processing (Fig. 13) is used in conjunction with all other probability of detection curves representing the other values of N to obtain the modified receiver operating characteristic curves for the CAD model responding to multiple ping events.

(U) A total of nine sets of modified ROC curves are generated. Each set includes a parameterization of the average signal-to-noise ratio for each of the curves produced.

(U) Examples of the modified ROC curves are shown in Figs. 14, 15, 16, 17, 18, 19, and 20. Figure 14 resulted from mapping the curve in Fig. 12 with the set of curves in Fig. 5. The other figures resulted from mapping Fig. 13 with the set of curves in each of Figs. 6, 7, 8, 9, 10, and 11 respectively.

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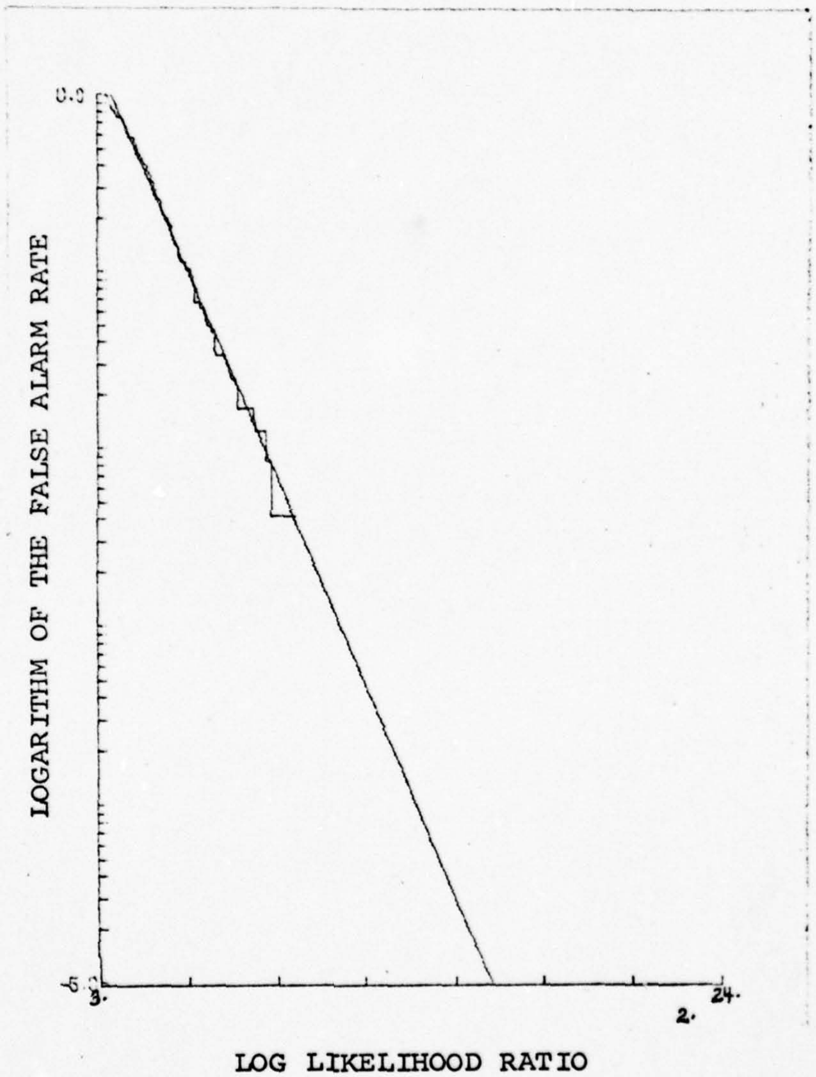

Fig. 13 False Alarm Rate Curve for Noise Data After Processing by the CAD Model

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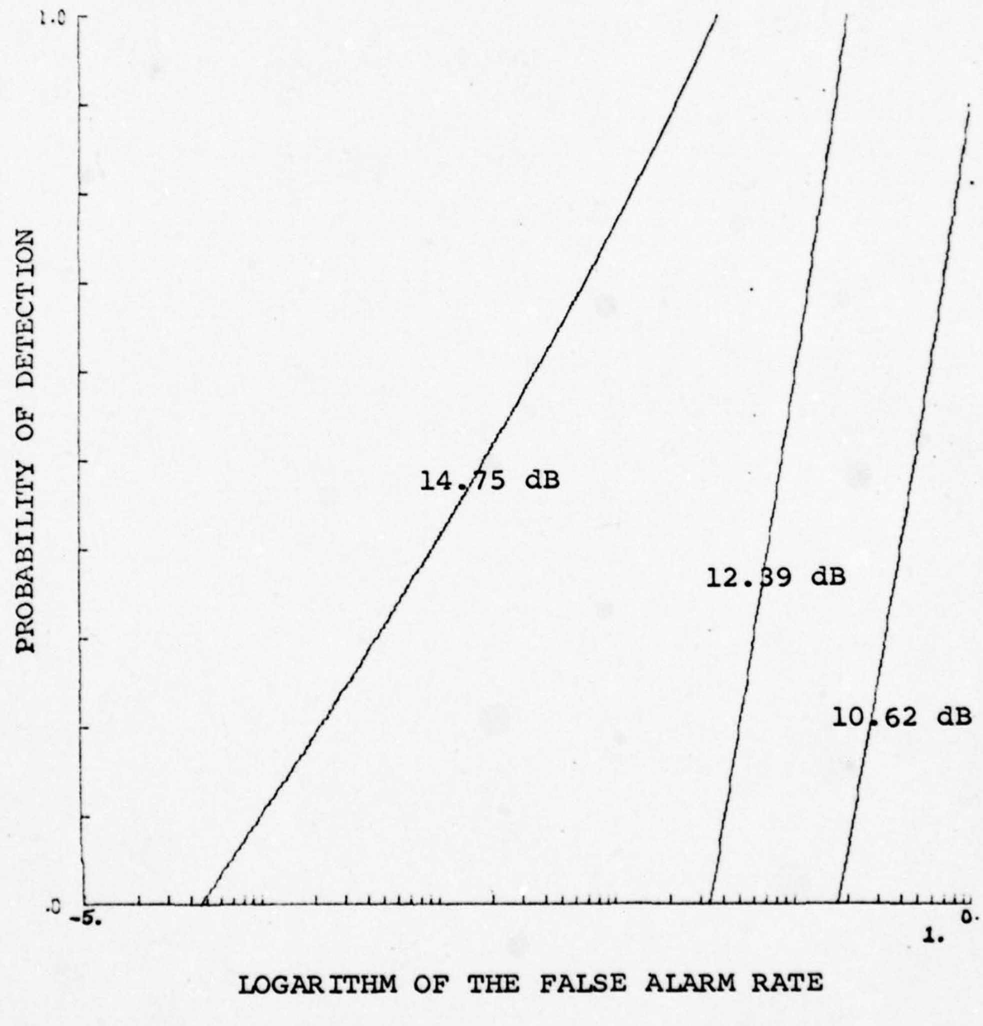

Fig. 14 Modified Receiver Operating Characteristic Curve for CAD Model Operating on Single Ping Events (N=1)

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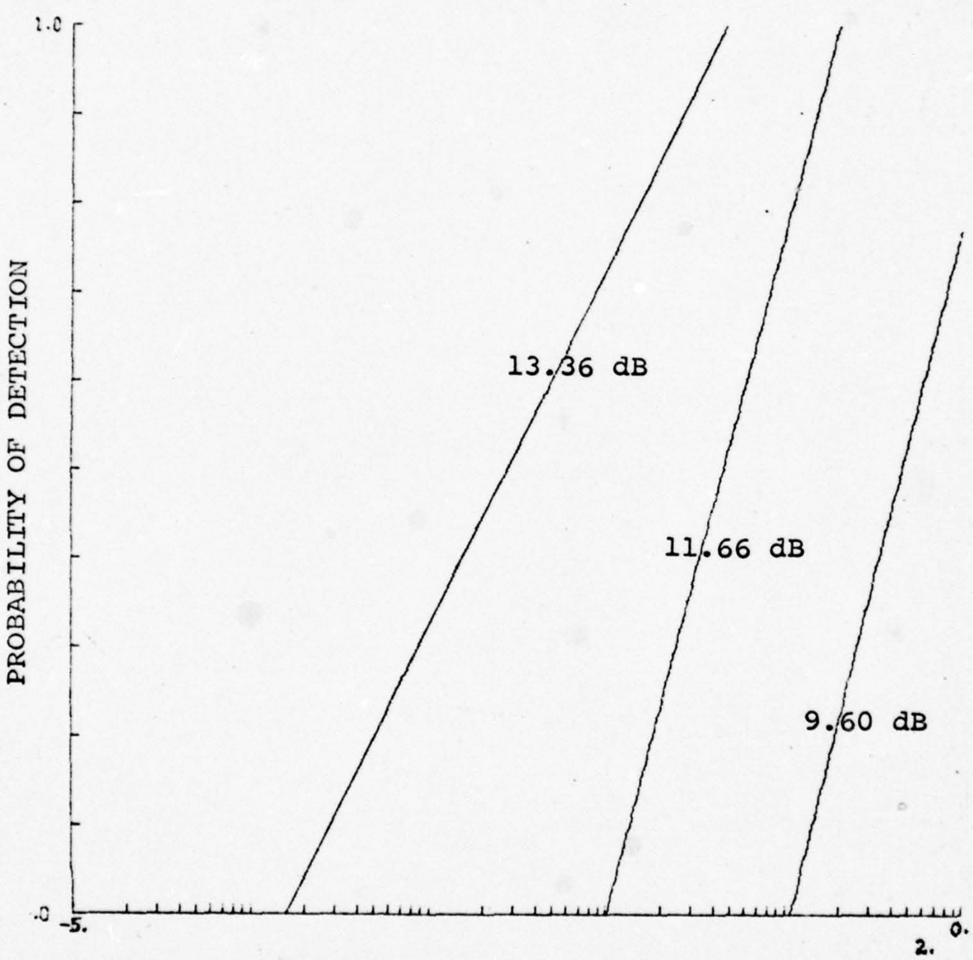

Fig. 15 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 2 Pings

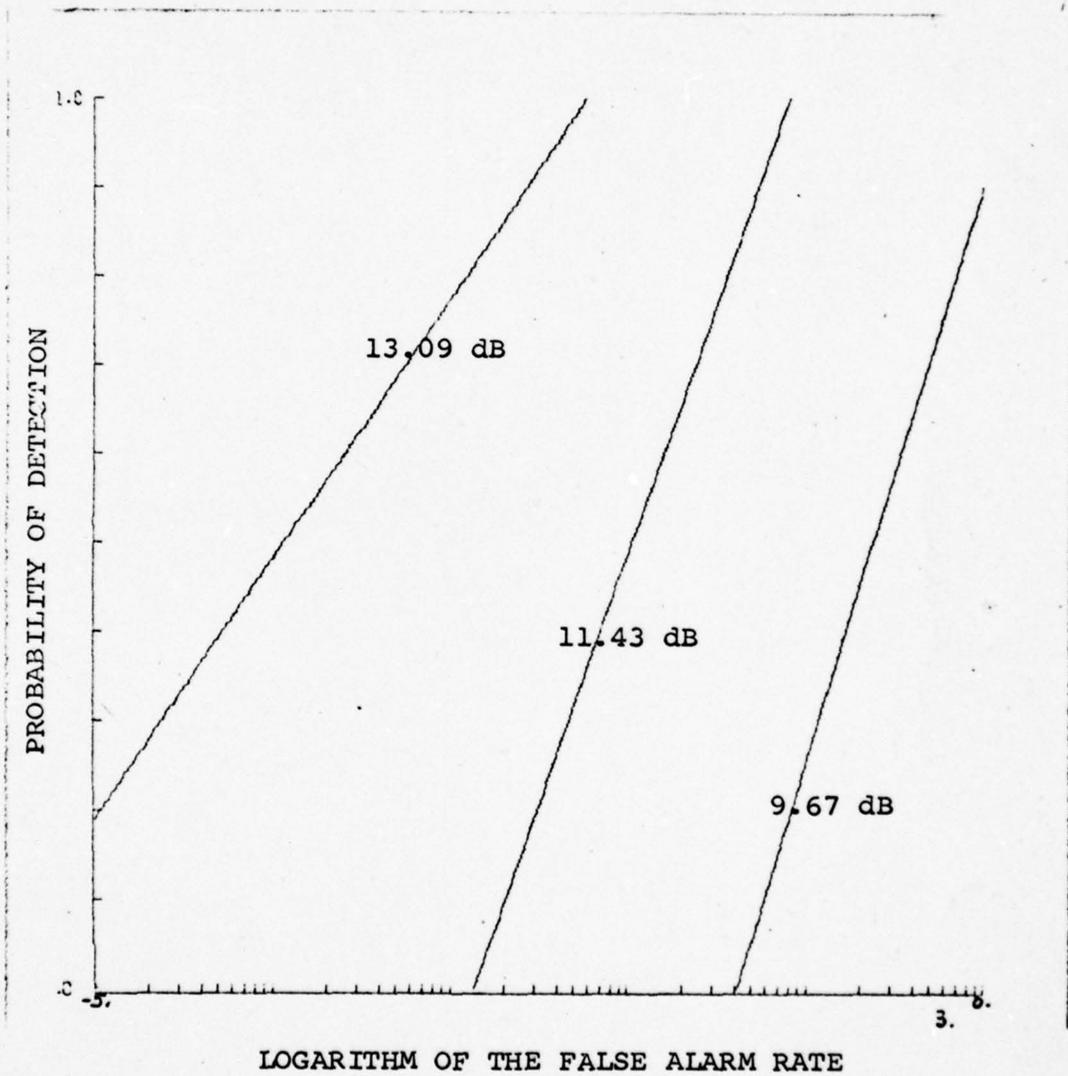

Fig. 16 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 3 Pings

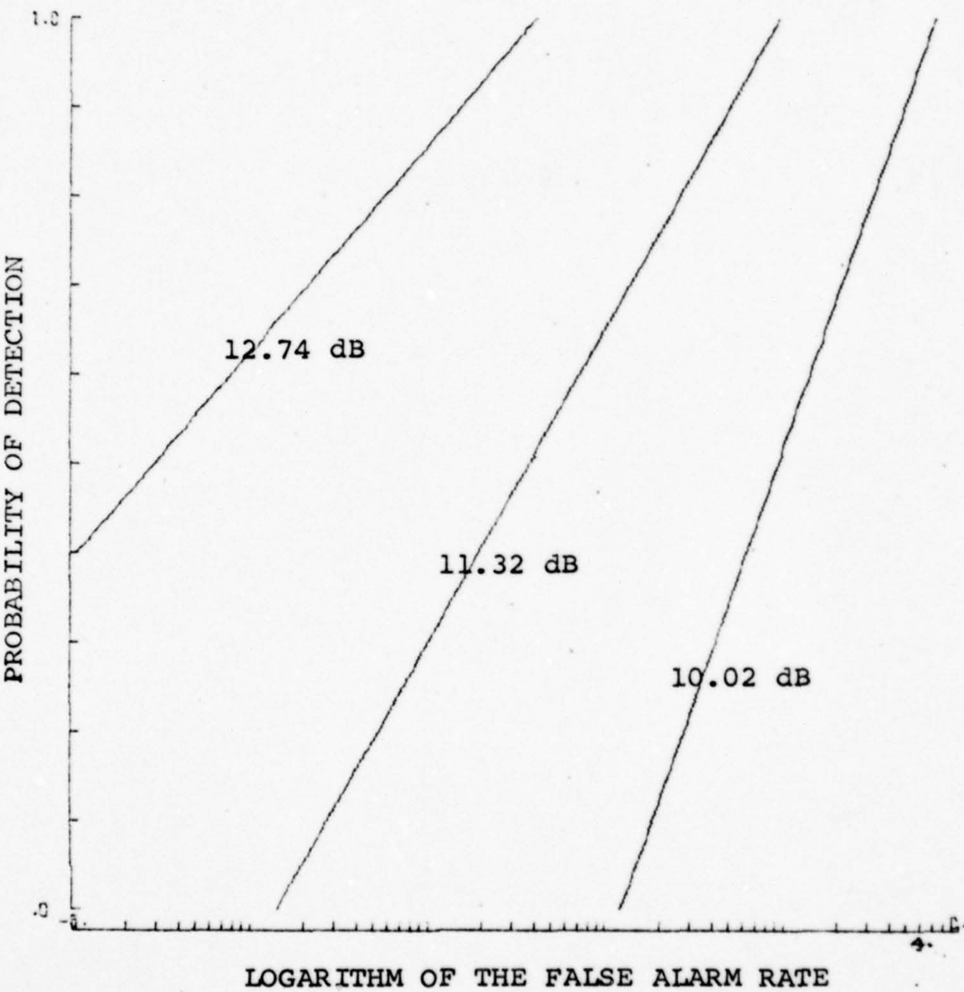

Fig. 17 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 4 Pings

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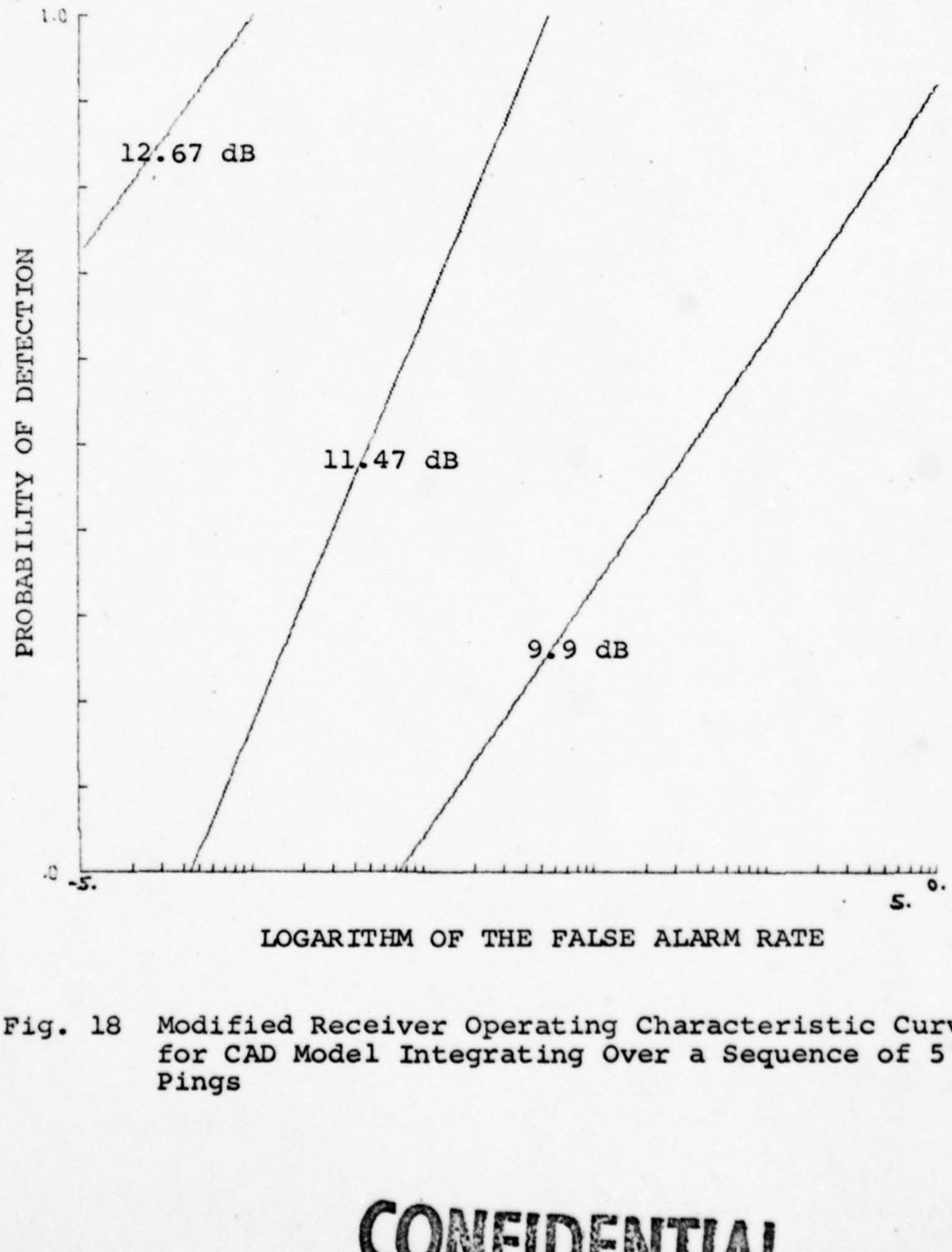

Fig. 18 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 5 Pings

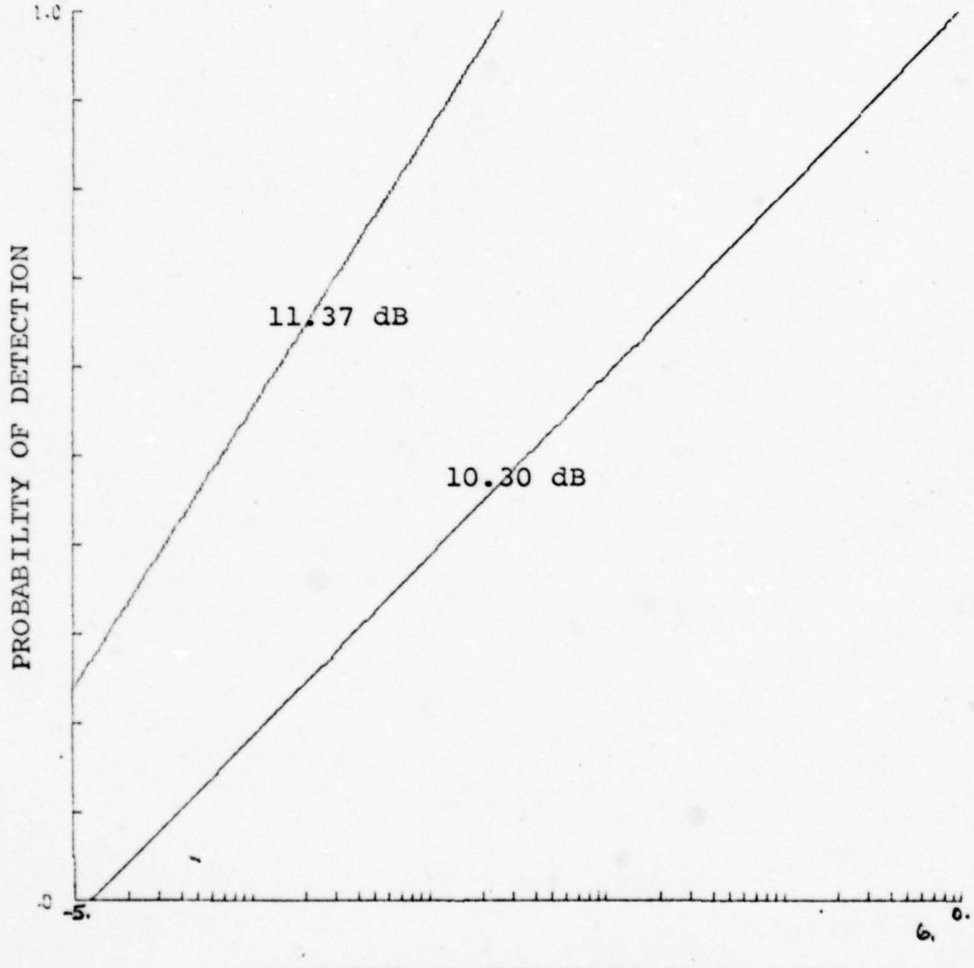

Fig. 19 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 6 Pings

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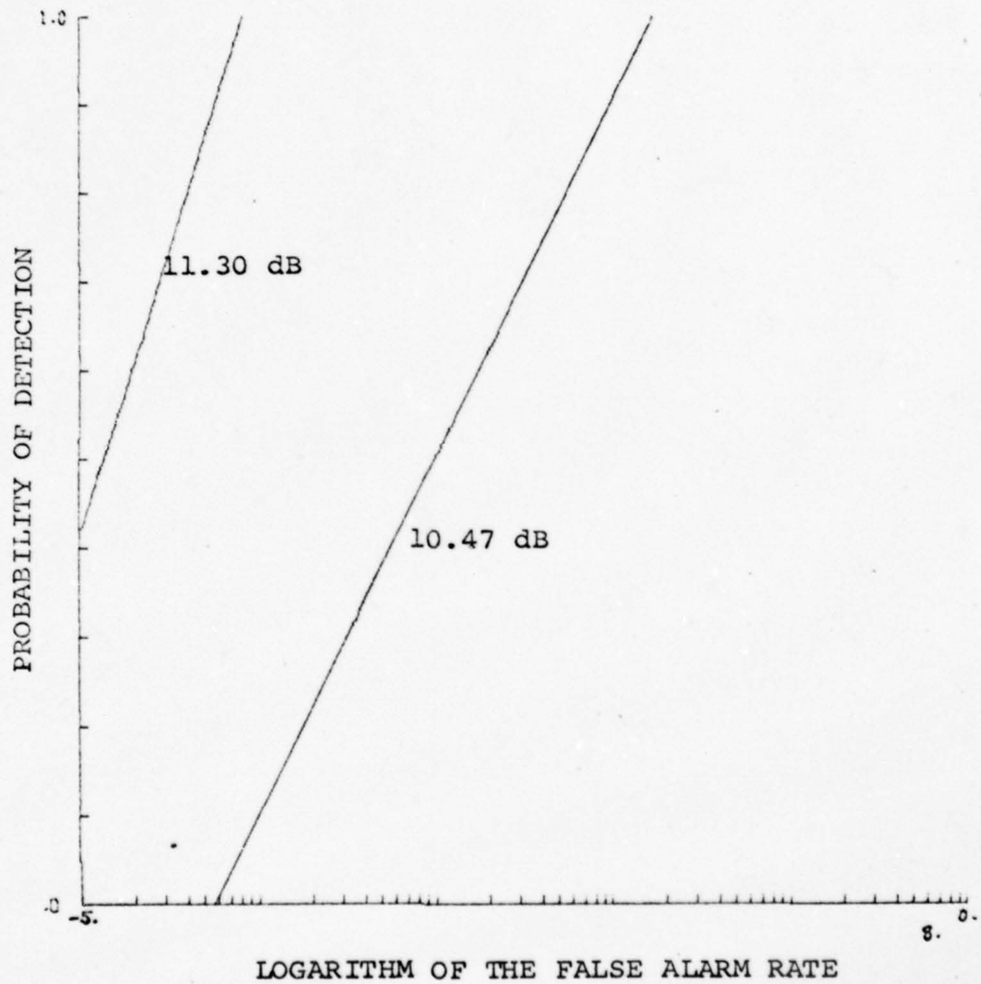

Fig. 20 Modified Receiver Operating Characteristic Curve for CAD Model Integrating Over a Sequence of 8 Pings

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2.2.4 Comparison of CAD Performance with Operator Performance

(U) In addition to the absolute measure of CAD performance provided by the modified ROC curves described above it is desirable to obtain a performance comparison relative to the sonar operator. The procedures to be followed to obtain this comparison are described below. Section 2.2.4.1 describes the procedures to be used to obtain a single ping performance comparison. Section 2.2.4.2 describes the procedures to be used to obtain a multiple ping performance comparison.

2.2.4.1 Single Ping Comparison of CAD Performance with Operator Performance

(U) As described above the operator responses will be logged for each ping cycle in the TECHEVAL data. The possible responses are: N-No Signal, Q-Questionable, W-Weak, M-Medium, and S-Strong. These five response levels provide information about four operator threshold levels, i.e. Strong, Medium or Better, Weak or Better, and Questionable or Better. By combining the operator response data with the measured signal log likelihood ratios four curves of probability of detection vs. log likelihood ratio are obtained. Typical curves of this type are shown in Fig. 21.

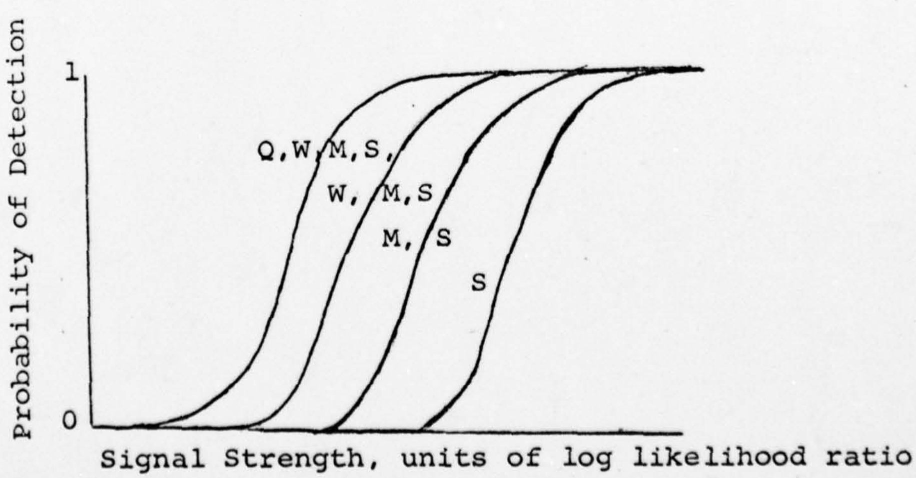

Fig. 21 Probability of Detection Curve for Operator Responses

(U) It is possible to associate a false alarm rate with each of the operator response threshold levels through the relation,

$$(FAR)_{OP} = \int_0^\infty P_D(\ell) \cdot \left[\frac{dFAR(\ell)}{d\ell}\right] \cdot d\ell ,$$

where

$FAR(\ell)$ is the single ping false alarm rate function described earlier, and

$P_D(\ell)$ is one of the four curves describing operator performance.

In words $\left[\frac{dFAR(\ell)}{d\ell}\right] \cdot d\ell$ is the differential rate at which noise events occur with log likelihood ratios between ℓ and $\ell+d\ell$, and P_D is the probability that the noise event will be called when it does occur.

(U) The four false alarm rates associated with the four operator response thresholds may be compared with the false alarm rates associated with a perfect threshold device set to obtain 50% probability of detection at the same log likelihood value achieved by the operator. This approach provides the desired single ping comparison of the CAD model with the operator in terms of a difference in false alarm rate at the same probability of detection.

(U) An alternate approach to obtain the desired single ping comparison is to determine where a perfect threshold would need to be set to obtain the same false alarm rates as the operator and then to compare log likelihood ratios required for 50% probability of detection.

2.2.4.2 Multiple Ping Comparison of CAD Performance with Operator Performance

(U) From the CAD modified ROC curves described earlier a curve of decrease in signal-to-noise ratio required for 50% probability of detection (from that required when N=1) vs. number of pings (N) of integration is generated. Past studies of operator performance indicate that the operator achieves a gain of approximately 5 log (N) under favorable conditions. It is expected that the performance of the CAD model will also follow a curve of the form K log (N). By determining a best fit value for K a comparison of CAD multiple ping performance with operator multiple ping performance is obtained.

APPENDIX A

1. THE CAD MODEL

(U) This appendix is intended to provide some insight into the computer-aided detection model.

(U) The logical flow of data within the CAD model is shown in Fig. 1. The natural time base for an active track detection model is the ping interval, and this is depicted in Fig. 1 by the layers labeled echo cycles N-1, N, and N+1. The CAD model uses two different types of input information, that stored in a master status file and that coming from the sonar signal processor.

(U) Information pertaining to possible target tracks is stored in the master status file in the form of multiple ping event packages. Each of these packages consists of data which was obtained from one or more ping cycles and which shows promise of defining a target track. During echo cycle N, single ping event packages are formed from ping N and used as input to the model. When viewed in this way it is seen that the goal of the model is to combine single ping event packages from each echo cycle in an optimal way with multiple ping event packages from the master status file to produce an updated master status file. The information in the updated master status file is then passed to the next echo cycle for use as input by the track detection model during that echo cycle.

(U) The track strength of each possible track represented in the status file can, during any echo cycle, be tested against a threshold, and if the threshold is exceeded the information in the multiple ping event package can be used to drive a display.

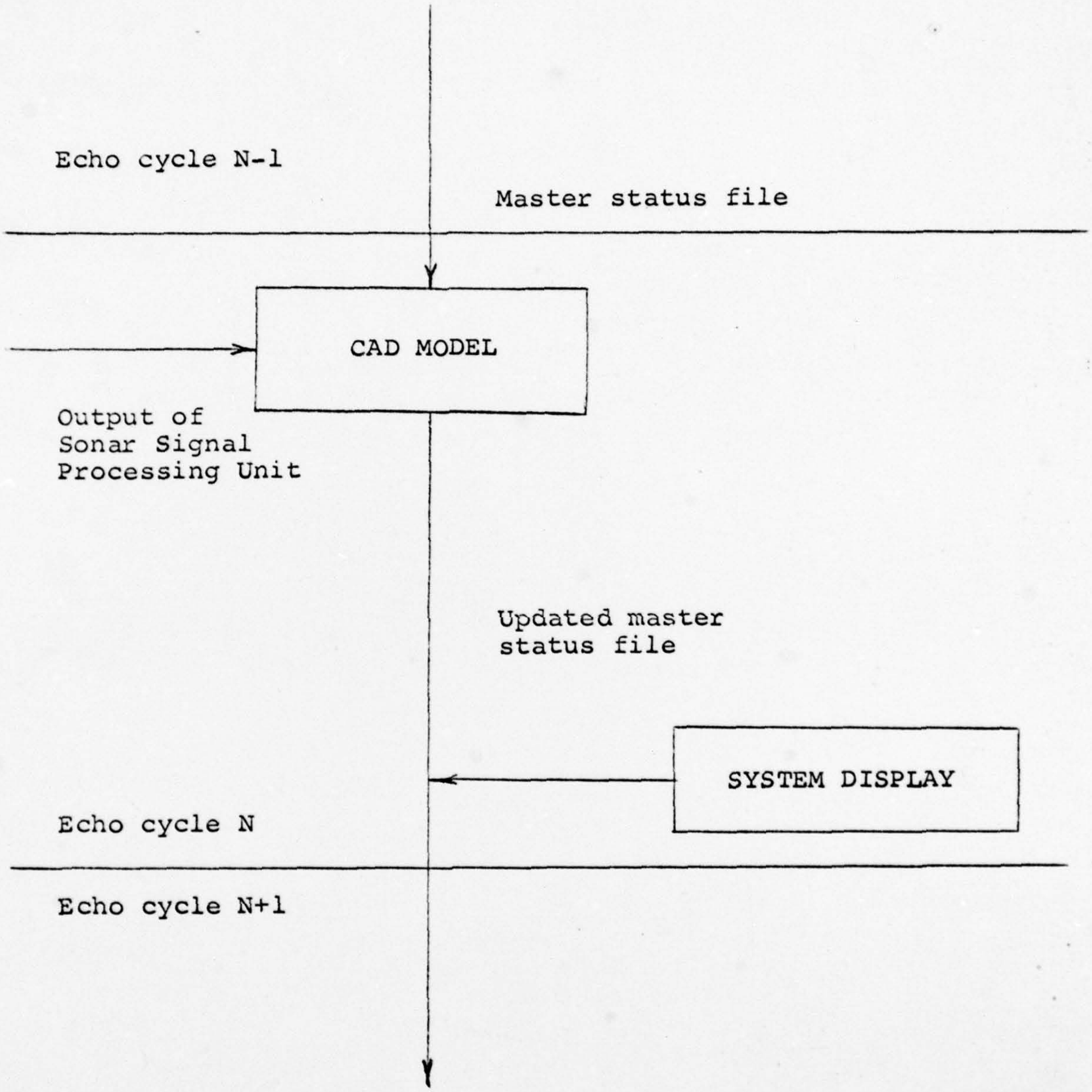

FIG. 1 LOGICAL FLOW OF DATA

2. EVENT PACKAGES

2.1 Multiple Ping Event Packages

(U) As mentioned above, information pertaining to possible target tracks is maintained in the master status file. It is important to note that the storage required does not depend on the duration of a target track but only on the number of possible tracks under investigation at a given time. The number of tracks under investigation is controlled by a retention threshold employed in the main processing loop of the detection model. A possible target track is defined in computer memory as long as its track likelihood ratio exceeds the retention threshold. The amplitude of the retention threshold is a system parameter and is determined by the amount of computer memory available for event package storage.

(U) A possible target track is defined by a multiple ping event package in the master status file. Each package contains the following four functional quantities used to describe a possible target track:

(1) Logrithm of the track log likelihood ratio
(2) Range position of the latest processor output peak to contribute to the track
(3) Expected range position in next ping of a peak belonging to the track
(4) Previous ping bit sequence.

(U) The log of the track likelihood ratio provides a measure of the track strength. The likelihood ratio is the ratio of the probability that the events which compose the track represent signal divided by the probability that they represent noise. When a new signal is received and linked

with a track, the track likelihood ratio is updated by multiplying the old track likelihood (that of the multiple ping event) by the single signal likelihood ratio (that of the single ping event) and dividing by a loss factor dependent upon the deviation of the single signal's range position from the range position expected for a track sample. To avoid the multiplication involved in computation, it is convenient to carry the log of the likelihood ratio.

(U) The expected range position of the track on a given ping is determined by linearly extrapolating the position of the track peaks on the previous two pings. The expected range position and the previous range position of a track can be combined to produce an estimate of target range rate.

(U) The previous ping bit sequence is a string of bits conveying information about the previous 24 pings. Each bit represents a previous ping and is set only if that ping contained a signal peak which belonged to the target track. A possible target track is presented to the display only if the previous ping bit is set. This feature is included in the track detection model to suppress display of tracks whenever pings occur that do not exhibit peaks belonging to the track. This procedure prevents spurious display of track remnants. Such a remnant occurs when a strong track suddenly disappears. In this case, the tracking logic will require a number of pings to eliminate a strong track history from consideration and the previous ping switch suppresses display during these pings.

2.2 Single Ping Event Packages

(U) The main function of the CAD model is to combine the single-ping information received from a sonar signal processing unit with the information from previous pings and

produce an updated master status file. The first step in this process is the conversion of processor output into single-ping event packages.

(U) Information received during an echo ranging cycle is divided into single ping event packages by the application of a threshold to the output of the sonar signal processing unit. It is often possible to pick a threshold sufficiently low to pass any useful signal and still sufficiently high that 95-99% of the noise will not exceed the threshold. The single ping event packages contain the range position of the event and the single ping log likelihood ratio associated with the event.

(U) The likelihood ratio, as applied to single events, is defined as the ratio of the probability that the event peak is a result of signal divided by the probability that it is a result of noise. The specific transformation from peak height to log likelihood ratio is dependent on the type of signal processing used and the average signal-to-noise ratio expected when a signal is present. Often the exact equation for transformation from peak height to log likelihood ratio is quite complicated. The transformation equations for a replica correlator and the statistical wave period processor have been investigated in some detail, however, and it has been found that in the area of interest a linear transformation from peak height to log likelihood ratio is very accurate.

(U) As mentioned above the specific transformation also depends on the signal-to-noise ratio expected when a signal is present. To specify this quantity the minimum signal-to-noise ratio which will permit detection in a reasonably small number of echo cycles is used. In this way the system is optimum for signals near the minimum detectable level.

3. MASTER STATUS FILE UPDATING

(U) The next stage in the combination of single-ping information with multiple-ping events is to update the master status file and thus to produce a new set of multiple-ping history for future pings.

(U) Updated entries are made in the master status file in three functionally different ways. These are:

(a) Large single ping events,

(b) Single ping events which are linked with multiple ping events, and

(c) Large multiple ping events.

(U) The procedures used for making each type of entry are described below.

3.1 Large Single Ping Events

(U) If the log likelihood ratio of a single ping event exceeds the retention threshold, then an entry to the master status file will be made. On the first echo ranging cycle this is the only way an entry can be made. The expected range position is set equal to the single event range. The log of the track likelihood ratio is set equal to the single ping log likelihood ratio.

3.2 Linked Events

(U) When a single-ping event occurs in a range position in the vicinity of the expected position of a target track, the possibility of a "link" between the single-ping event and the multiple ping event history arises. The linking process is the most essential part of the target track detection model since it is the vehicle for achieving ping-to-ping integration along a track.

(U) In the description of the linking procedure, the following notation will be useful. Suppose that a multiple ping event package describes a possible target track with track log likelihood ratio L_T and that a signal sample belonging to the track occurred on the previous ping at range R_T. Further, let R_E denote the expected position on the next ping of a sample belonging to this track. Now let χ denote a sample on the next ping whose log likelihood ratio is L_S and whose range position R_S falls within a interval of investigation about R_E.*

(U) The decision as to whether the sample χ belongs to to the track defined by the event package is made by a determination of a link likelihood ratio L. Two quantities enter into the computation of L, an amplitude likelihood ratio A and a range deviation loss D.

(U) The amplitude likelihood ratio A is determined by adding the single ping log likelihood ratio L_S to the track log likelihood ratio L_T. A is thus a measure in the amplitude domain of the probability that the single ping sample belongs to the track.

(U) The range deviation loss D is a function of the amount d that the single ping range R_S deviates from the expected track position R_E (i.e. $d=|R_S-R_E|$). The algorithm used in computing D has been derived by assuming that the distribution of signal peaks belonging to a track about the expected track position R_E is Gaussian with mean R_E and a specified standard deviation σ. Analytic methods do not readily yield a value

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(U) *The length of the interval of investigation is a system parameter determined by maximum target range rates. It is chosen so that samples at range positions outside the interval could not reasonably be expected to belong to the target track.

for σ but a value of 25 independent samples is presently being used with some success. The actual algorithm used in computing D is

$$D = - \ell n \left(\frac{N}{\sigma \sqrt{2\pi}}\right) + \frac{d^2}{2\sigma^2}$$

where N is the numbers of samples in a resolution interval at the signal processor output.

(U) After the deviation loss D has been computed, the link likelihood ratio L of the single ping event linking with the track is computed as $L = L_A - D$. The quantity L is thus a two-dimensional joint likelihood ratio giving a measure in both the amplitude and range domains of the probability that the single ping event links with the multiple ping event package. Accordingly, if L exceeds the retention threshold, it is decided that a link has occurred and a new multiple ping event package is formed. The four quantities describing the new estimate of the track are updated as follows:

(1) track log likelihood ratio is set to L

(2) range position of the track on the "previous" ping is set to R_S

(3) the expected position of the track on the next ping is computed by linearly extrapolating R_T and R_S

(4) a "1" is placed in the previous ping bit sequence since a link occurred on this ping.

(U) In processing linked events, the CAD model follows the procedure outlined above to determine which single ping events can link to a multiple ping event package and produce a new multiple ping event package in the updated master status file. At the end of an echo cycle, the updated master status file contains the latest estimates of possible target tracks and it in turn will become the previous ping history in processing of future echo cycles.

(U) In one special case, the processing outlined above is modified. In the test for a link, two gain factors G_P and G_T are computed. The purpose of these gain factors is to indicate those situations in which the track and the signal peak combine so well that a link is assured.

(U) The signal peak gain factor G_P is computed as the signal peak likelihood ratio minus the deviation loss and is a measure of how much the track alone is enhanced by the presence of the signal peak. The track gain factor G_T is computed as the track log likelihood ratio minus the deviation loss and is a measure of how the signal peak benefits from the presence of the track.

(U) Whenever G_T and G_P both exceed a specified threshold, a special link is made. In this case, a new multiple ping event package is formed and both the old multiple ping event package and the single signal peak are deleted from further consideration in the present ping. This procedure allows strong tracks to be processed rapidly and also prevents spurious tracks which may occur when the strength of a large track would allow it to link with fairly small noise peaks.

3.3 Large Multiple Ping Events

(U) In the case of linked events a multiple ping event was removed from the master status file and updated with a linking single ping event. The updated multiple ping event was then entered in the updated master status file. There are some multiple ping events in the master status file, however, which are not linked in a given echo cycle. This may be due to a single bad echo ranging cycle or it may stem from the loss of a contact.

(U) When a multiple ping event package does not link with any single ping event, its track log likelihood ratio is degraded by a fixed amount. If the degraded likelihood ratio still exceeds the retention threshold, a new multiple ping event package is placed in the updated master status file. The track likelihood ratio of the new package is set equal to the degraded likelihood ratio above. The previous peak position remains the same and the expected peak position on the next ping is computed by extrapolating the previous expected position. A zero is placed in the previous ping bit sequence to indicate that no link occurred on this ping.

(U) A multiple ping event package will thus be propagated in the master status file as long as its track likelihood ratio exceeds the retention threshold. A target track can thus be maintained even though a peak does not occur on every ping.

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13. ABSTRACT

This report contains a discussion of the processing procedures which will be used to validate the computer-aided detection (CAD) model. (U)

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